Fermi National Accelerator Laboratory

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A Study into Lowering Beam Trajectories in PO1

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A Study Into Lowering Beam Trajectories in P01

Allan Sondgeroth
September 1, 1995

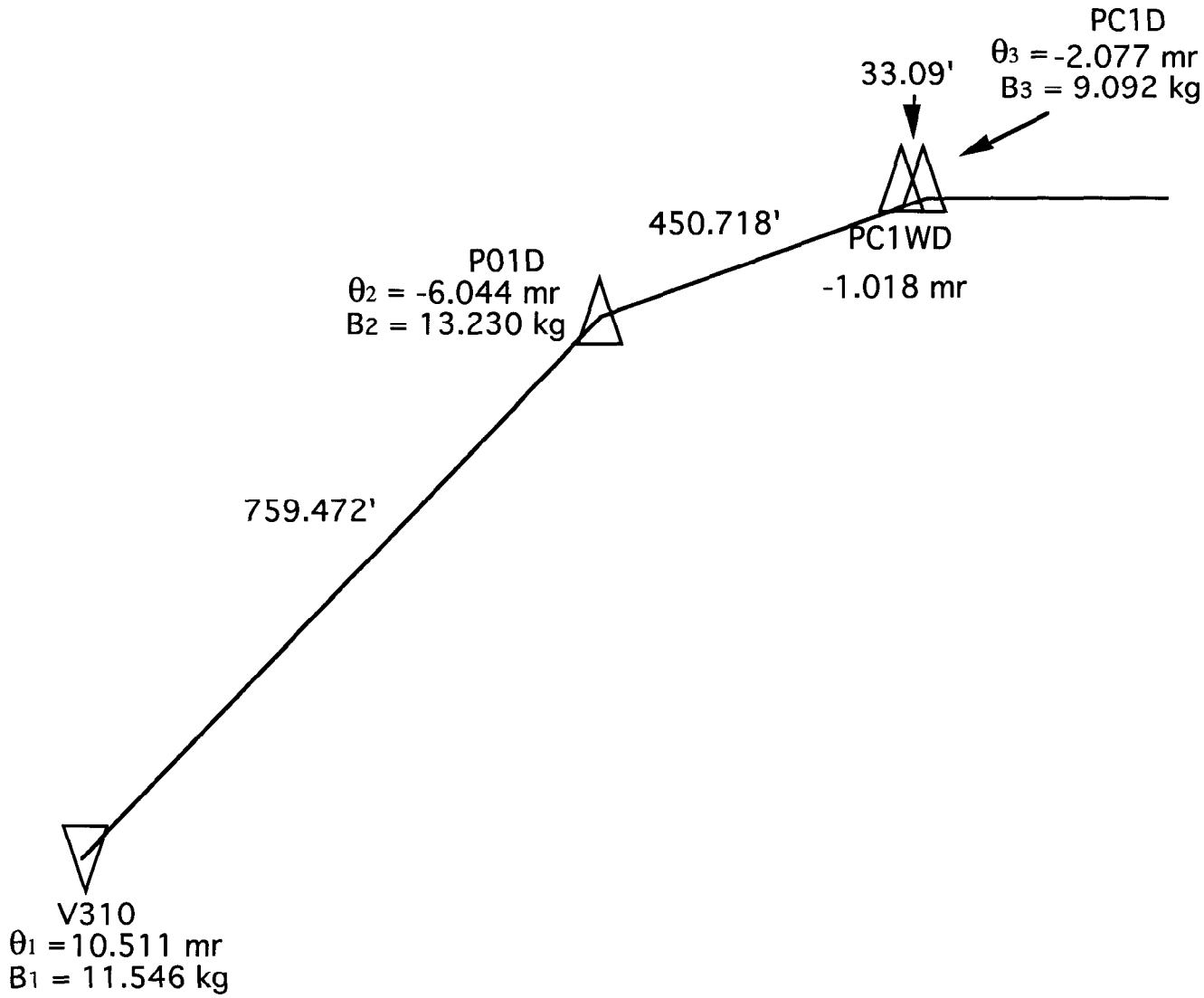
This document describes what changes would be needed to lower the primary beams coming from switchyard into enclosure P01 without changing trajectories in the downstream enclosures. This study was done at the request of the Research Division Head. Calculations were performed by Gaston Gutierrez and Allan Sondgeroth.

There is a 680 foot pipe buried in the ground between Enclosure E and P01 which allows primary beam to travel from the switchyard area to the research division area. This pipe is approximately 25 years old and has started to leak. The effects of the leaky pipe can be catastrophic to the transportation of the Proton area beams.

The vacuum group has devised an ingenious way of repairing a leak from the inside using remotely controlled grinders, patchers,welders and cameras mounted on carts that can be pulled into the pipe. A typical patch adds approximately one half of an inch of material which, in turn, restricts the aperture of the pipe. This pipe has three seperate beams runing through it split in the verticle plane. Pwest is the highest beam in the pipe and, in at least one location, the center of the beam clears the top of the pipe by one and one half inches. If a leak were to develop at a low spot in the pipe the patch to fix the leak might create an obstruction for the beam. Hence, the request from the Research Division Head.

Methodology:

We first looked at the PCenter beam optics to determine which magnetic fields could be changed to lower positions by two inches at the upstream end of P01 while keeping the position at the downstream end unchanged. As it is now configured the center of the PCenter beam is two inches above the center of the pipe so after these proposed changes the beams would effectively be centered in the pipe. This also gives PWest the added clearence required. The optics for PCenter are on the following page. The drawings show only the bend points and angles of the main bend strings.



The following are the calculations performed to determine the change in angles required to produce the desired effect.

$\Delta\theta_1 = 2"/(759.5'x12") = 0.219$ mr ==> $\theta_1' = 10.292$ mr

The verticle angle in V310 must be lowered by 0.219 mr to lower the position in P01D by 2". Therefore, θ_1 will need to be 10.292 mr. We can also scale the original magnetic field by the same percentage as the change in angles.

$\Delta\theta_1/\theta_1 = 0.219$ mr / 10.511 mr = 0.021

B_1' = 11.546 kg-(0.021x11.546 kg) = 11.303 kg

V310 consists of a string of eight magnets. The last magnet is rotated by 13.967 degrees past the verticle plane so it produces a bend in the horizontal plane. To keep the horizontal trajectory unchanged the rotation in this magnet must be increased to compensate for the resultant reduction in the magnetic field in V310. Here θ_1 and θ_1' indicates the bending angle of the last magnet only.

$\theta_{1H} = \theta_1(\sin \phi) = 1.319$ mr(sin 13.967 deg) = 0.318 mr
$\theta_{1v} = \theta_1(\cos \phi) = 1.319$ mr(cos 13.967 deg) = 1.279 mr

$\theta_1' = \theta_1(0.021\ \theta_1) = 1.291$ mr
$\theta_{1v}' = \theta_1'(\cos \phi) = 1.291$ mr(cos 13.967 deg) = 1.252 mr

We can now calculate the new angle in the following way.

$\phi' = \tan^{-1}(0.318$ mr/1.252 mr) = 14.252 deg

Next we calculated the new angle for PC1D. We chose PC1D over PC1WD because we don't need to be concerned with a rotational change.

$\Delta\theta_3 = 2"/(483.79'x12") = 0.344$ mr ==> $\theta_3' = -2.421$ mr
$\Delta\theta_3/\theta_3 = 0.344$ mr / 2.077 mr = 0.166
$B_3' = 9.092$ kg+(0.166x9.092 kg) = 10.601 kg

Finally, we calculated the new angle for P01D. Since the final trajectory remains unchanged, all of the angle changes added together should be equal to zero. Therefore;

$\Delta\theta_1+\Delta\theta_2+\Delta\theta_3 = 0$
$\Delta\theta_2 = -\Delta\theta_1-\Delta\theta_3 = 0.219+0.370 = 0.589$ ==> $\theta_2' = -5.455$ mr
$\Delta\theta_2/\theta_2 = 0.589$ mr / 6.044 mr = 0.097
$B_2' = 13.230$ kg-(0.097x13.230 kg) = 11.947 kg

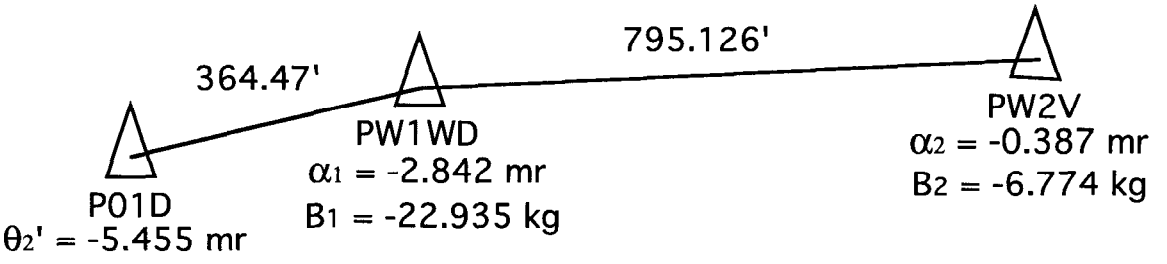
With these calculated values in hand we next made some transport runs with vary codes inputed into V310, P01D and PC1D. We also put position contraints at the middle of P01D, two inches lower than the existing beam, and at the exit of P01. The value of the second constraint was the existing beam position. The results are as follows;

$\theta_1' = 10.282$ mr	$B_1' = 11.299$ kg
$\theta_2' = -5.448$ mr	$B_2' = 11.927$ kg
$\theta_3' = -2.453$ mr	$B_3' = 10.705$ kg

We used a trial and error method to establish the new rotation value for the last magnet in the V310 string. After several iterations the following angle was found to reproduce the existing horizontal trajectory down the beamline.

$\phi' = 14.281$ deg

With PCenter concluded we turned our attentions to PWest. We used the same methods as above and the new bend angles for V310 and P01D. Also, since the bend point for PW1WD is not in the same z location as PC1D the elevation changes, therefore PW2V is needed to compensate for the change in angle. Our predicted values are as follows:



$\alpha_1' = -3.134$ mr $B_1' = -22.965$ kg
$\alpha_2' = -0.439$ mr $B_2' = -7.685$ kg

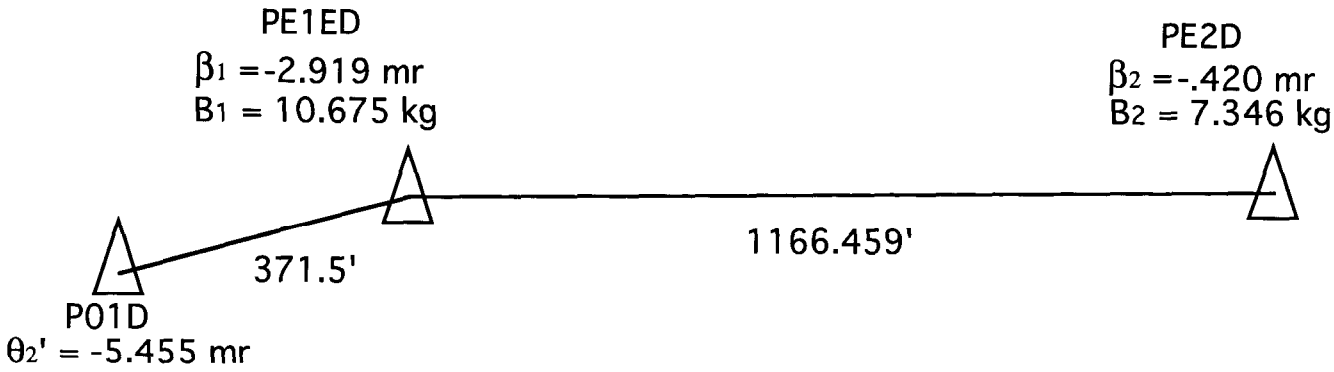
PW1WD1 is a string of five rotated magnets. Again, we would need to change the angle of rotation of the magnets to keep the horizontal trajectory unchanged. Our predicted change is as follows:

$\omega = -6.228$ deg
$\omega' = -6.862$ deg

Our transport runs gave these numbers:

$\alpha_1' = -3.154$ mr $B_1' = 22.967$
$\alpha_2' = -0.440$ mr $B_2' = -7.711$kg
$\omega' = -6.906$ deg

Finally, we calculate values for PEast:



The following are our predicted values:

β_1' = -3.256 mr B_1' = 10.759 kg
β_2' = -0.453 mr B_2' = 7.923 kg

Again, we would need to change the angle of rotation of the magnets to keep the horizontal trajectory unchanged. Our predicted change is as follows:

ψ = 15.43 mr
ψ' = 17.55 mr

This is what transport gave us:

β_1' = -3.255 mr B_1' = 10.766 kg
β_2' = -0.451 mr B_2' = 7.899 kg
ψ' = 17.10 mr

The table below is a list of elements that would need to be lowered and/or rotated and by how much:

Element	Lower(inches)	Rotate Clockwise
Common Elements		
V310_7	0.10	
V310_8	0.12	0.31 deg
P00H	0.17	
P00V	0.18	
P00WC	0.19	
P01WC1	2.06	
P01D_1	2.09	
P01D_2	2.07	

	P01D_3	2.07	
	P01D_4	2.03	
	P01WC2	2.03	
	P01SHIELD	1.98	
	PE1E/PW1W_1	1.94	
	PE1E/PW1W_2	1.89	
	PE1E/PW1W_3	1.84	
	PE1E/PW1W_4	1.79	
	PE1E/PW1W_5	1.74	
	P01WC3	1.74	
PCenter Elements			
	PC1DUMP	0.82	
	PC1WC1	0.32	
	PC1Q1	0.26	
	PC1WD_1	0.19	
	PC1WD_2	0.15	
	PC1WD_3	0.10	
PWest Elements			
	PW1WC0	0.90	
	PW1BD	0.83	
	PW1WD_1	0.66	0.68 deg
	PW1WD_2	0.59	0.68 deg
	PW1WD_3	0.54	0.68 deg
	PW1WD_4	0.50	0.68 deg
	PW1WD_5	0.48	0.68 deg
	PW1SEM	0.48	
	PW1V	0.43	
	PW1BS	0.42	
	PW1WC2	0.42	
PEast Elements			
	PE1WC1	0.72	
	PE1V1_1	0.70	
	PE1V1_2	0.68	
	PE1ED_1	0.62	1.67 deg
	PE1ED_2	0.57	1.67 deg
	PE1ED_3	0.54	1.67 deg
	PE1ED_4	0.51	1.67 deg
	PE1ED_5	0.48	1.67 deg
	PE1ED_6	0.46	1.67 deg
	PE1ED_7	0.44	1.67 deg
	PE1ED_8	0.43	1.67 deg
	PE1ED_9	0.42	1.67 deg
	PE1Q1	0.46	

PE1BS	0.42
PE1V2_1	0.40
PE1V2_2	0.41
PE1Q2	0.41
PE1WC2	0.40
PE1SEP_1	0.40
PE1SEP_2	0.40
PE1SEP_3	0.39
PE1V3	0.39
PE1WC3	0.39

Attached is a man hour estimate for this job from Rich Stanek.

Fermilab

RD/Mechanical Support Department--MS#219
Wilson Hall 11th Floor--Ext. 3519

August 29, 1995

TO: Bob Trendler

FROM: Rich Stanek

SUBJECT: Lowering Elements in P01

The Mechanical Support Department (MSD) has estimated the effort required to lower and in some cases rotate the elements in the P01 enclosure. We are estimating only the incremental effort caused by the lowering of the elements and not the total work needed to get P01 ready to run. Barring any unforeseen circumstances, we believe that the following would hold true.

Mechanical		
New saddles & supports, as necessary	2 men x 2 weeks	Carpenter
Prep supports & adjustments	2 men x 2 weeks	Carpenter
Cryogenics		
Lower & rotate PW1WD string	2 men x 2 weeks	Noe
Vacuum		
Modify beam tube & vacuum pumps	2 men x 2 weeks	Fagan
Water		
Modify LCW system, as necessary	2 men x 1 week	Fagan
Alignment*		
As founds & final alignment	3 men x 5 weeks	Sager
Mechanical support	2 men x 2 weeks	Carpenter

* Includes some estimate of the need to do tie-ins to Enclosure E

Rigging		
Adjust upstream elements	1 crew x 3 days	Guthke

Total Manpower Effort

22 man weeks of mechanical tech time
15 man weeks of alignment tech time
3 crew days of rigging time

Total Project Duration = 10 calender weeks (given that some things can be done in parallel)